The Nedre Dalälven River Landscape in Central Sweden - a hot-spot for mosquito (Diptera:Culicidae) diversity

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First published online: 16th October 2018

Abstract: The floodplains of the River Dalälven, Central Sweden, have previously been known for enormous abundance of mosquitoes causing unbearable nuisance, but since mosquito control measures by Biologisk Myggkontroll (BMK) commenced in 2002, the area's beautiful landscape and high biodiversity can be more appreciated. The floodplains are the central part of the UNESCO Nedre Dalälven River Landscape Biosphere Reserve as well as the location of various protected areas. The rich biodiversity also includes mosquitoes, although these insects are rarely considered in the study of biodiversity. We analysed mosquito data collected by the BMK surveillance program from 2001 until 2017 for species richness and assemblages of the mosquito fauna in the floodplains of the River Dalälven, and the nearby Creeks Vretaån and Kilsån. The mosquito species richness of the Nedre Dalälven River Landscape included 30 species in the present study, and three to eight species could potentially be added according to other studies, which then includes more than 70% of all known mosquito species in Sweden. The location of the floodplains at the Limes Norrlandicus, the border between southern and northern vegetation zones, is reflected in the mosquito fauna that includes species commonly found in Northern Sweden as well as more southern species. The mosquito species richness of the region is similar to the species richness observed in other floodplain areas in Central and Southern Europe. Hydrological conditions of the Lake basins of the River Dalälven floodplains varied from frequent flooding with high amplitude to almost no flooding. As expected, the hydrological variations were reflected in the mosquito assemblages, with high prevalence of floodwater mosquitoes in the flood-prone areas and more homogenous assemblages in the areas less subject to flooding. In conclusion, the River Dalälven floodplain area is considered a mosquito diversity hot-spot for Sweden and for Europe.
Journal of the European Mosquito Control Association 36: 17-22, 2018

Keywords: mosquito diversity, mosquito species richness, floodplains, River Dalälven, Sweden, Europe

Introduction

The floodplains of the River Dalälven in Central Sweden are considered an area of extraordinary biodiversity in a spectacular landscape. Here, the River Dalälven coincides with the so-called *Limes Norrlandicus* that marks the boundary to Northern Sweden and the transition from southern to northern climate and vegetation zones. This location and the natural disturbance by irregular but frequent flooding allows for a multitude of wetland habitats such as marshes, wet meadows, swamps and bogs. The region holds a large number of rare and red-listed species of various taxa including mosses, beetles and birds, and is protected as Natura 2000, nature reserves, and a national park, as well as included in the Ramsar List of Wetlands of International Importance. In 2011, the region was designated by UNESCO´s Man and the Biosphere Programme (MAB) as a Biosphere Reserve due to the unique natural and cultural environments.

Floodplains and their wetlands provide habitat for a wide range of species leading to high biodiversity (Keddy, 2000). Biodiversity includes all organisms, but diversity of mosquitoes (Diptera: Culicidae) might not be considered positive by many (Schäfer *et al.*, 2004). The floodplains of the River Dalälven have been known for their enormous abundance of floodwater mosquitoes, and since 2002, biological larval control using *Bacillus thuringiensis israelensis* (Bti) is performed by Biologisk Myggkontroll (BMK) within Nedre Dalälven Utvecklings AB (Schäfer & Lundström, 2014). The mosquito fauna of the area has been subject to a number of investigations, e.g. Jaenson (1986), Blackmore & Dahl (2002) and Schäfer *et al.* (2008). Since 2001, BMK performs annual mosquito surveillance in seven municipalities, covering the entire River Dalälven floodplain area and two additional creek areas. Here we summarize the mosquito surveillance data from the years 2001 to 2017 with respect to species composition at different parts of the Nedre Dalälven River landscape.

Materials and Methods

The Nedre Dalälven River landscape includes the floodplains of the River Dalälven along a 120 km stretch from the city of Avesta in the West to the town of Älvkarleby in the East, where the river reaches the Baltic Sea (Figure 1). In this area, the river forms a series of lakes at different elevations, connected by rapids. The lakes differ in their hydrological conditions due to water regulations for hydro-electric power. Comparing the spring and summer flood occurrence over a ten-year period, Lake Färnebofjärden is most subject to frequent and high amplitude water level fluctuations, followed by Lake Bysjön, Lake Bäsingen, Lake Untrafjärden and the area at Creek Vretaån. Lake Hedesundafjärden is less frequently and less severely affected by floods, as is the area at Creek Kilsån. The two remaining areas, Lake Bramsöfjärden and Lake Storfjärden, are very rarely subject to distinct flood situations.

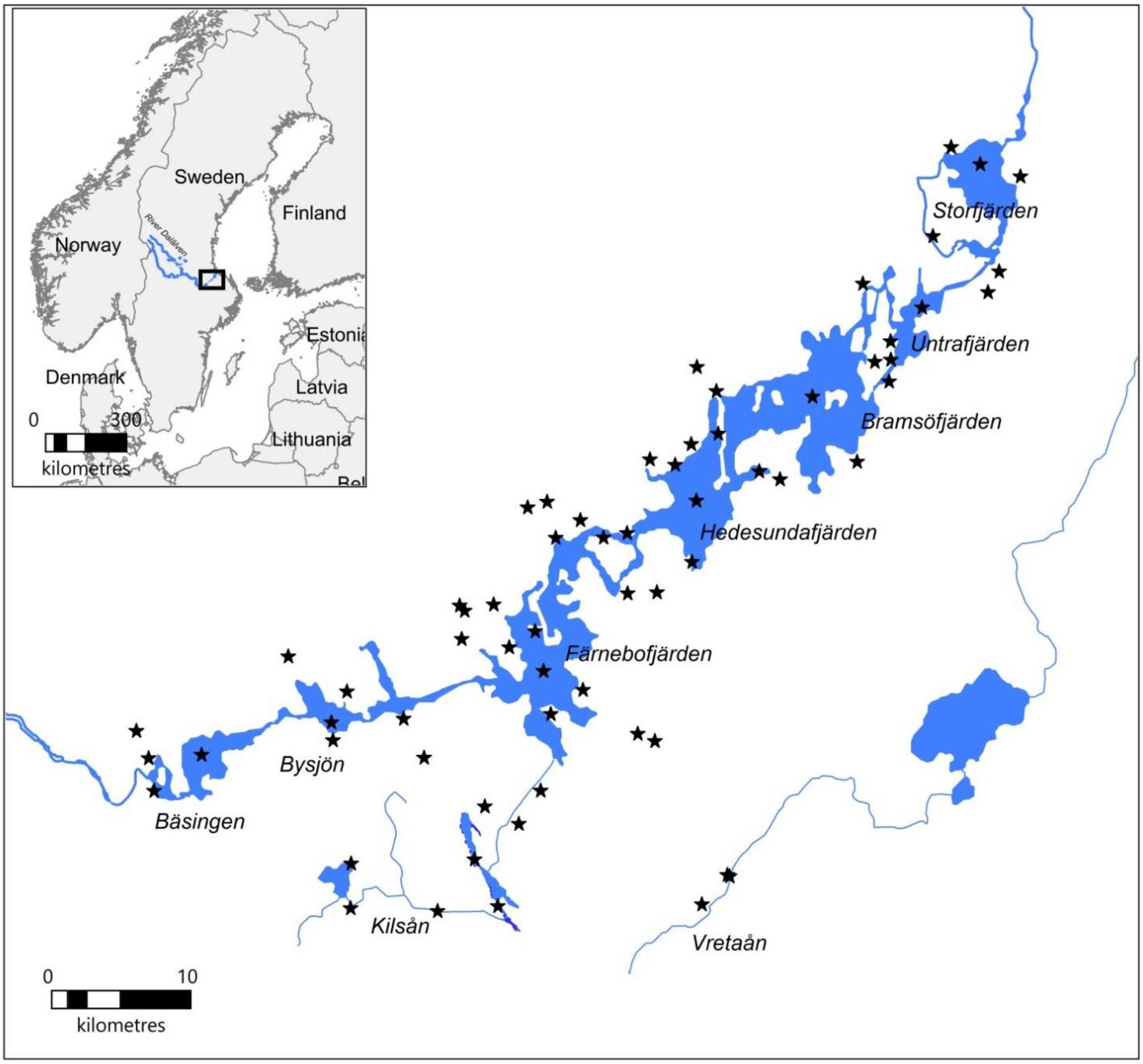

Figure 1: The location of the Nedre Dalälven River Landscape in Sweden, the lakes of the River Dalälven floodplains and the additional creek areas that are included in the mosquito surveillance by Biologisk Myggkontroll. The black stars mark mosquito sample sites, but not all sites were sampled during all years from 2001 to 2017.

The surveillance of blood-seeking female mosquitoes by BMK was performed using CDC miniature light traps baited with carbon dioxide for one night per trap site every second week from early May (week 21) to late September (week 37) each year. This trap type is commonly used for mosquito surveillance and captures almost all mammophilic species (Becker *et al.*, 2010, European Centre for Disease Prevention and Control, 2014). The total number of trap sites varied during the years and ranged from 23-25 sample sites in the first years (2001-2003) to 38-42 trap sites during the latter years (2012-2017). Also, the number of traps per lake area differed between lakes and years, thus we did not include total abundance data in the present overview of the mosquito fauna but focused on species compositions.

Species identification was based on the morphological keys provided by Gutsevich *et al.* (1974), Wood *et al.* (1979), Becker *et al.* (2003) and Becker *et al.* (2010). All mosquitoes collected in a trap were identified but for large samples, a random subset of up to approximately 2000 mosquitoes per trap and night was chosen for identification. We also used the concept of mosquito functional groups (MFG) that was initiated by Schäfer & Lundström (2001) and refined to 10 well defined MFG by Schäfer *et al.* (2004). More recently recorded mosquito species in Sweden were MFG classified by Lundström *et al.* (2013). The groups are provided with a code and the number code 1 denotes that the species lays eggs on water surface and 2 denotes that the species lays eggs on the soil. The letter codes (a-e) indicate the total classification based on overwintering life stage (egg, larva or female), preferred blood meal host (mammals, birds or amphibians) and the number of generations per year (univoltine or multivoltine).

Results

Altogether, 3,691,907 female mosquitoes were included in the present study and 30 mosquito species were recorded for the Nedre Dalälven River landscape (Table 1). These species represented nine out of the ten MFG defined for Swedish mosquitoes. Eighteen species were found during all years and at all lakes. These common mosquito species included *Coquillettidia richiardii* (MFG 1A); *Anopheles claviger* (MFG 1B); *An. maculipennis* s.l., *Culiseta alaskaensis*, and *Cs. bergrothi* (MFG 1C); *Culex pipiens/torrentium* (MFG 1D); *Ae. annulipes*, *Ae. cantans*, *Ae.*

communis, *Ae. diantaeus*, *Ae. intrudens* and *Ae. punctor* (MFG 2A); *Ae. cinereus*, *Ae. rossicus*, *Ae. sticticus* and *Ae vexans* (MFG 2B); *Aedes geniculatus* (MFG 2C) and *Cs. morsitans* and *Cs. ochroptera* (MFG 2E). In total, the most common species was *Ae. sticticus* (65.15%), followed by *Ae. cinereus* (8.60%) and *Ae. communis* (8.37%). Among the rare species, represented by less than 0.01 % in all study areas, the following species could be noted: *Ae. excrucians* (only recorded from Creek Kilsån), *Ae. flavescens* (found at four areas), *Ae. hexodontus* (recorded from Lake Färnebofjärden and Lake Storfjärden), *Ae. pullatus* (found at four areas), *Ae. dorsalis* (recorded from Lake Hedesundafjärden and Creek Vretaån), *Ae. nigrinus* (recorded only from Hedesundafjärden), and *Cx. territans* (recorded from Lake Bäsingen and Lake Färnebofjärden).

Most species were recorded from Lake Färnebofjärden and Lake Hedesundafjärden (Table 1). Around each of these lakes, 26 mosquito species were listed. The records for Lake Färnebofjärden covered nine functional groups and included the uncommon species *Ae. flavescens*, *Ae. hexodontus*, *Ae. pullatus*, *Cx. territans* and *Cs. fumipennis*. At Lake Hedesundafjärden, rare species included the only record for *Ae. nigrinus*, as well as records for *Ae. pullatus*, *Ae. dorsalis*, and *Cs. fumipennis*. Here, eight mosquito functional groups were found.

The mosquito species compositions in the various lakes of the River Dalälven were similar, but the species assemblages differed (Table 1, Figure 2). Lake Bäsingen, Lake Bysjön, Lake Färnebofjärden and Creek Vretaån were strongly dominated by floodwater mosquito species (≥ 75% for the MFG 2B), with *Ae. sticticus* (63-82%) as the dominating species. At Lake Hedesundafjärden and Lake Untrafjärden, floodwater mosquito dominance was less distinct (60-62% for MFG 2B) and the proportion of snow pool mosquitoes increased (27-33 % for MFG 2A), with *Ae. communis* as the most common species (18 and 26%, respectively). At Lake Hedesundafjärden, also MFG 1A (13%) with *Cq. richiardii* was common. At Creek Kilsån, the mosquito species assemblage was more evenly distributed between MFG 2A and MFG 2B, with *Ae. intrudens* and *Ae. sticticus* dominating in the respective groups. At Lake Bramsöfjärden and Lake Storfjärden, MFG 2A and *Ae. communis* were dominating, especially at Lake Bramsöfjärden (71% for MFG 2A). At Lake Storfjärden, group 1A with *Cq. richiardii* was the second most abundant group and species (31%).

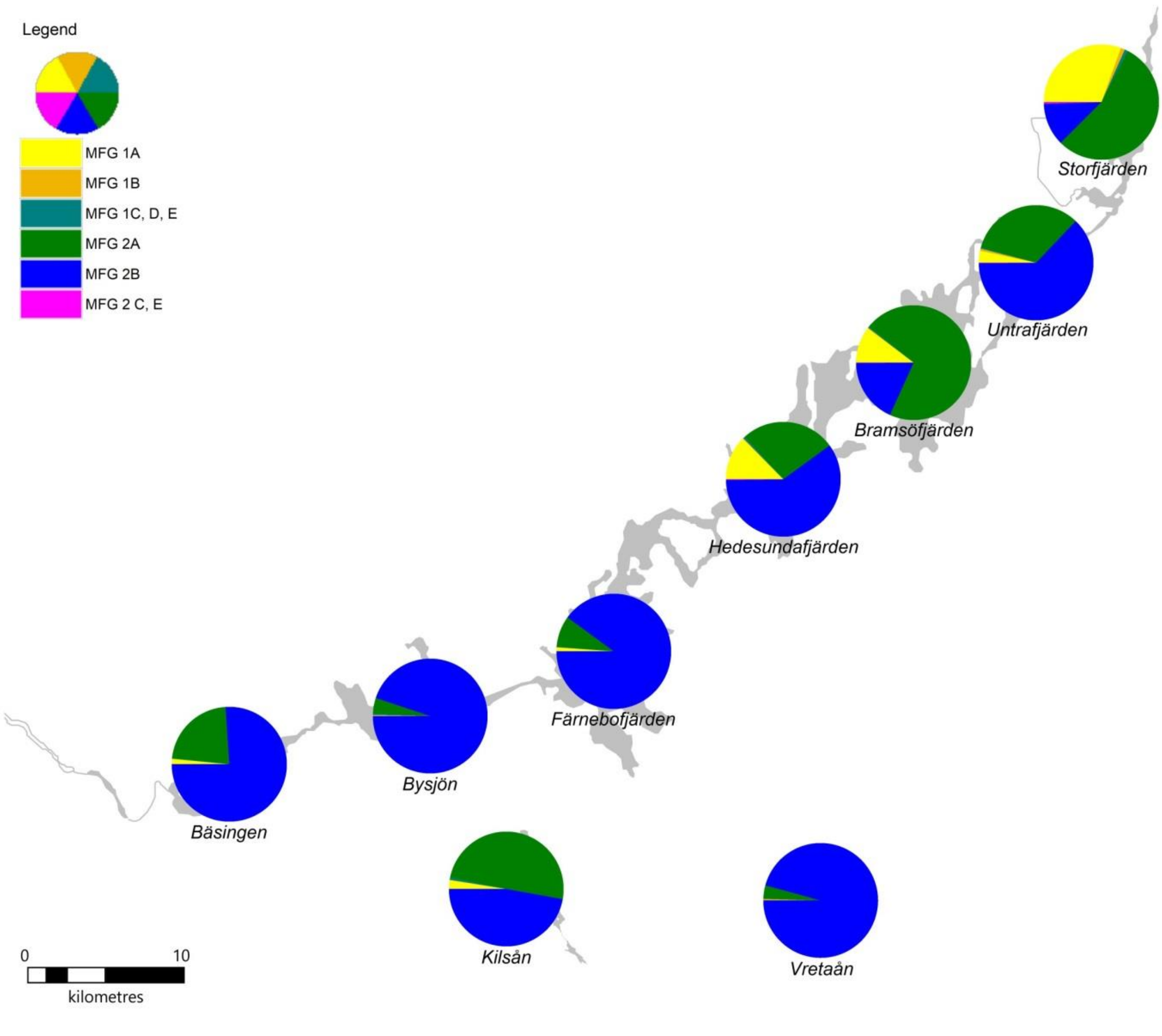

Figure 2: Mosquito functional group assemblages at the lakes of the River Dalälven floodplains and two additional creek areas in the Nedre Dalälven River Landscape, based on mosquito surveillance by Biologisk Myggkontroll with CDC miniature light traps from 2001 to 2017.

Table 1: The mosquito species sorted following mosquito functional groups (MFG) collected in different areas of the Nedre Dalälven River Landscape during the years 2001 to 2017, given as percentage of total catch per area and in total. Mosquitoes were sampled with CDC miniature light traps baited with carbon dioxide fortnightly from May to September each year.

	MFG	Bäsingen	Bysjön	Färnebofjärden	Hedesundafjärden	Bramsöfjärden	Untrafjärden	Storfjärden	Kilsån	Vretaån	TOTAL
Coquillettidia richiardii (Ficalbi, 1889)	1A	1.44	0.15	1.05	12.59	10.21	3.32	30.57	2.47	0.07	2.44
Anopheles claviger (Meigen, 1804)	1B	0.03	0.03	0.06	0.14	0.30	0.62	1.19	0.03	0.31	0.11
Anopheles maculipennis s.l.	1C	0.08	0.10	0.10	0.37	0.10	0.16	0.77	0.37	0.04	0.13
Culiseta alaskaensis (Ludlow, 1906)	1C	0.04	<0.01	0.02	0.04	0.08	0.04	0.06	0.04	0.01	0.03
Culiseta annulata (Schrank, 1776)	1C	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Culiseta bergrothi (Edwards, 1921)	1C	<0.01	0.02	0.03	0.04	0.04	0.02	<0.01	<0.01	<0.01	0.02
Culex pipiens/torrentium	1D	0.11	0.27	0.05	0.12	0.11	0.12	0.08	0.27	0.17	0.09
Culex territans (Walker, 1856)	1E	<0.01	-	<0.01	-	-	-	-	-	-	<0.01
Aedes annulipes (Meigen, 1830)	2A	0.07	0.09	0.14	0.12	0.22	0.11	0.03	2.26	0.21	0.20
Aedes cantans (Meigen, 1818)	2A	3.39	0.40	0.74	2.30	5.93	2.15	0.96	4.55	0.68	1.26
Aedes cataphylla (Dyar, 1916)	2A	<0.01	<0.01	0.02	<0.01	0.17	0.01	<0.01	0.01	0.10	0.02
Aedes communis (DeGeer, 1776)	2A	10.30	1.87	4.89	17.68	52.26	25.51	48.47	2.47	0.92	8.34
Aedes diantaeus (Howard, Dyar & Knab, 1912)	2A	7.03	0.25	0.72	3.29	9.57	2.11	1.06	0.08	0.02	1.41
Aedes excrucians (Walker, 1856)	2A	-	-	-	-	-	-	-	<0.01	-	<0.01
Aedes flavescens (Muller, 1764)	2A	-	<0.01	<0.01	-	-	-	-	<0.01	<0.01	<0.01
Aedes hexodontus (Dyar, 1916)	2A	-	-	<0.01	-	-	-	<0.01	-	-	<0.01
Aedes intrudens (Dyar. 1919)	2A	0.69	1.20	1.48	0.84	0.47	0.63	0.22	38.17	0.11	2.39
Aedes pullatus (Coquillett, 1904)	2A	<0.01	-	<0.01	<0.01	-	-	-	<0.01	-	<0.01
Aedes punctor (Kirby, 1837)	2A	0.83	0.65	0.73	2.53	2.21	2.33	4.04	2.11	1.79	1.06
Aedes caspius (Pallas, 1771)	2B	-	-	-	<0.01	<0.01	-	0.06	-	-	<0.01
Aedes cinereus (Meigen, 1818	2B	11.27	4.78	6.39	31.40	8.49	12.61	7.79	13.63	5.45	8.62
Aedes dorsalis (Meigen, 1830)	2B	-	-	-	<0.01	-	-	-	-	<0.01	<0.01
Aedes nigrinus (Eckstein, 1918)	2B	-	-	-	<0.01	-	-	-	-	-	<0.01
Aedes rossicus (Dolbeskin, Gorickaja & Mitrofanova, 1930)	2B	0.87	7.81	8.04	1.52	0.11	8.22	0.11	7.27	1.70	6.84
Aedes sticticus (Meigen, 1838)	2B	62.76	79.91	73.93	25.87	8.95	36.91	2.32	24.97	81.61	65.16
Aedes vexans (Meigen, 1830)	2B	1.00	2.32	1.52	0.90	0.57	4.89	1.76	1.13	6.72	1.76
Aedes geniculatus (Olivier, 1791)	2C	<0.01	<0.01	<0.01	<0.01	0.04	0.01	<0.01	<0.01	-	<0.01
Culiseta fumipennis (Stephens, 1825)	2E	-	<0.01	<0.01	<0.01	-	0.02	<0.01	0.00	-	<0.01
Culiseta morsitans (Theobald, 1901)	2E	0.03	0.09	0.06	0.21	0.13	0.18	0.44	0.08	0.06	0.08
Culiseta ochroptera (Peus, 1935)	2E	0.04	0.03	<0.01	0.04	0.02	0.01	0.07	0.06	0.01	0.01
Number of species		23	23	26	26	22	22	24	24	22	30
Number of functional groups		9	8	9	8	8	8	8	8	7	9
Number of individuals		170,454	277,201	2,503,877	227,331	97,164	184,177	43,483	112,276	75,944	3,691,907

Discussion

The number of mosquito species recorded for the Nedre Dalälven region by the BMK surveillance program during the years 2001 to 2017 included 30 species, compared to 23 species mentioned in Schäfer *et al.* (2008) and 26 species in the respective provinces of Uppland, Västmanland, Gästrikland and Dalarna in Lundström e*t al.* (2013). The species list in Schäfer *et al*. (2008) included *Ae. detritus* (Haliday, 1833), which was not found in the mosquito surveillance programme presented here. The species was sampled with one specimen in the wet meadows 2001, and two specimens in the swamps in 2001, all sites located at Lake Färnebofjärden. Blackmore and Dahl (2002) found *Ae. euedes* (Howard, Dyar & Knab, 1912) in their study at a site at Lake Färnebofjärden and this species was not present in our samples. Also, all identification was based on morphological characters, thus species complexes were not further investigated in this surveillance programme. The *Culex pipiens* complex was investigated by Hesson *et al.* (2011) and both *Culex pipiens* Linnaeus, 1758 and *Culex torrentium* Martini, 1925 were confirmed for the Nedre Dalälven region. The *Anopheles maculipennis* complex was studied in detail by Jaenson *et al*. (1986) and confirmed An. *messeae* Falleroni, 1926 and *An. beklemishevi* Stegnii & Kabanova, 1976 for the general region, but it is unclear if this specifically included the Nedre Dalälven River Landscape. Comparing the present list of species to Lundström *et al*. (2013) showed that *Ae. nigrinus* could be added to the species list for Gästrikland and *Cs. fumipennis* to the list for Gästrikland, Dalarna and Uppland. Additional species recorded for the provinces of Gästrikland, Dalarna, Västmanland or Uppland included *Ae. leucomelas* (Meigen, 1804), *Ae. riparius* (Dyar & Knab, 1907) and *Cs. subochrea* (Edwards, 1921) (Lundström *et al*., 2013). Adding the species confirmed by other studies to our list results in 33 mosquito species for the Nedre Dalälven River Landscape, and up to potentially 38 mosquito species based on the province records. This includes more than 70% of all known mosquito species in Sweden and comprises a number of rare species.

Sampling blood-seeking female mosquitoes with CDC miniature light traps baited with carbon dioxide is a standard method for mosquito surveillance (Becker *et al*., 2010). These traps sample a large variety of mosquito species, although some species are less likely to be collected in these traps, e.g. *Cx. territans* and *Cs. morsitans* (European Centre for Disease Prevention and Control, 2014). However, *Cs. morsitans* was a common species in our collections. Nevertheless, some species that were considered rare might very well be more common when other sampling methods, e.g. larval sampling, are used. Some of the species that occurred in low numbers in the Nedre Dalälven River landscape are common in other parts of Sweden, e.g. *Ae. hexodontus* and *Ae pullatus* were frequently collected in Northern Sweden (Schäfer & Lundström, 2001). Even with regard to mosquito species, the Nedre Dalälven River landscape seems to be a place where northern and southern species meet, leading to high species diversity.

Schäfer & Lundström (2001) observed a latitudinal gradient with an increasing number of mosquito species and functional groups from the north to the south of Sweden. In this study, 24 mosquito species from 9 functional groups (according to Schäfer *et al.* (2004)) were recorded for the location with highest mosquito diversity in the southern part of Sweden. It should be noted that the concept of functional groups was introduced by Schäfer & Lundström (2001) with 14 functional groups and refined by Schäfer *et al*. (2004) to 10 functional groups. In the present study, we recorded 30 mosquito species for Central Sweden, indicating higher mosquito diversity than expected. However, the present study summarized intensive mosquito sampling over 17 years, while the data in Schäfer & Lundström (2001) was based on collections from only one year. More intensive sampling in the area in Southern Sweden would very likely result in an increase of recorded mosquito species richness there as well.

The species assemblages reflected different hydrological conditions in the studied parts of the River Dalälven region, which is in accordance with Schäfer *et al*. (2008). The areas with high dominance of floodwater mosquitoes are more subject to flooding than the areas with a more homogenous mosquito fauna. Floodwater mosquitoes often occur in enormous numbers, thus it could also be possible that rare species might not be detected in the mass of floodwater mosquitoes. Nevertheless, we could record high species richness for Lake Färnebofjärden, where the highest number of mosquitoes were found as well, strongly dominated by *Ae. sticticus*. Lake Färnebofjärden, the location of a national park, is the most flood-prone area of the Nedre Dalälven River landscape. It occurs to be a hot spot for mosquito species although highly dominated by floodwater mosquitoes.

Other floodplains of large rivers in Europe have also been subject to mosquito investigations, providing information on mosquito species richness in similar areas. In the Upper Rhine Valley, Southwestern Germany, a mosquito surveillance program similar to the surveillance in the River Dalälven floodplains by BMK resulted in 30 mosquito species for the years 1991 to 1994, and three mosquito species could be added by larval sampling (Becker & Kaiser, 1995). In a more recent study, 25 mosquito species were found in the mosquito surveillance program during 2000 to 2009, and the total number of mosquito species recorded in Southwestern Germany had increased to 38 species, including two invasive species (Becker *et al*., 2011). In the floodplains of the Morava River, Slovakia, 28 mosquito species were recorded by sweep-net sampling (Strelková & Halgoš, 2012). In another part of the Morava River located in the Czech Republic, mosquito diversity included up to 37 species (Rettich *et al*., 2007). In Croatia, mosquito collections with CDC traps in the city of Osijek, located near the floodplains of the rivers Danube and Drava, from 1995 to 2004 resulted in 20 mosquito species (Sudarić Bogojević *et al*., 2009). The Danube River is also the centre for the UNESCO Danube Delta Biosphere Reserve with high recorded biodiversity, including 31 mosquito species (Prioteasa & Falcuta, 2010).

In conclusion, the mosquito species richness of the Nedre Dalälven River Landscape is similar to the species richness observed in floodplain areas in Central and Southern Europe. A total of 30 mosquito species were recorded in the present study, and three to eight more species could potentially be added to this list. Clearly, the floodplain area of the River Dalälven is a mosquito diversity hot-spot for Sweden and for Europe.

Acknowledgements

The authors want to thank Thomas Persson Vinnersten, Anna-Sara Liman, Björn Forsberg and Anna Hagelin for their contribution with mosquito sampling and identification.

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